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Autocorrelation type, timescale and statistical property in financial time series

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ABSTRACT

Earlier studies have documented that three types of autocorrelations exist in financial time series: sign, volatility, and return autocorrelation. In this paper, we examine how each type of the above autocorrelations affects the statistical properties of financial time series and its role in maintaining such statistical properties. Using three different shuffling series that correspondingly destroy each type of autocorrelation upon different timescales, we find that: (1) the statistical properties of the shuffling series significantly vary from the original ones; (2) volatility and return autocorrelations show greater impacts than sign autocorrelation; (3) the effects on the statistical properties are intensified as time scale expands; (4) the nonlinear component of autocorrelation is the major drive of the effect.

1. Introduction

The statistical properties of financial time series have received wide attention in literature. However, how the properties are determined still remains unresolved [1–4]. Recent works [5–9] have shown that autocorrelation plays a crucial role in forming statistical distribution. Hence, a quantitative description of autocorrelation influence will shed light on understanding statistical properties and improving the modeling of financial time series [5–11].

Some earlier papers [10–13] mainly focus on how autocorrelation evolves with time. They adopt detrended fluctuation analysis (DFA) [14] and multifractal detrended fluctuation analysis (MFDFA) [15] to quantify the decay of long-range correlation. They find that long-range correlation of price-change fluctuations shows slow decay as time extends. Moreover, the decay feature is well explained by the power-law function [10–13,16–18]. The price fluctuation of financial assets upon different timescales also presents similar results.

Other papers [18–21] further explore the influence of autocorrelation on the statistical properties of financial time series, especially the cause and persistence of fat tails. Those tests obtain crucial information to develop more accurate time series models [18,19]. By examining fat tails and long-range correlation [19], they show that the sampling timescale is associated with the correlation integral scale. When the sampling timescale is much smaller than the correlation integral scale, the fat tails are underestimated and deviate from their theoretical prediction values [18,19]. Moreover, by examining shuffling return series that destroy a sign or a return autocorrelation, Refs. [16,20,21] show that long-range correlation attributes to the cause of fat tails of financial time series. Ref. [19] investigates the influence of different correlations, such as volatility autocorrelation and non-asymmetric return-volatility autocorrelation, on statistical distribution and builds a

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general stochastic model to detect the time series. It is noteworthy that Ref. [22] also applies the shuffling series to analyze the singularity spectra of currency exchange rate fluctuations.

The research on the impact of autocorrelations on stock return makes remarkable progress in understanding the statistics and dynamics of financial time series. However, one can point out that there are two major challenges for the investigation as mentioned above. The first is in the fact that, for financial time series, there exists three types of autocorrelations, which lurk beneath the order of sign, volatility and return, respectively [22]. Hence, the investigation for the origin of fat tails only by sign and/or return autocorrelations is insufficient to capture the full picture of the influence of autocorrelation on statistical distribution. The second is that understanding the properties of center part and asymptotic behavior is also important to modeling the financial time series and describing the statistical properties.

In the same vein of literature [21,23], three shuffling series are created by destroying each of the three types of autocorrelation. When examining the statistical properties, including fat tails, center part and asymptotic behavior, of the shuffling series and original ones, we find that there exists a great variation between the properties of the original and shuffling series. Moreover, the volatility and return autocorrelation show a greater impact than sign autocorrelation. As time scale expands, the effect on the statistical properties grows stronger. Further, our tests support that the nonlinear component of the autocorrelation is the major drive of the effect. Our paper contributes to the literature by further understanding the relationships among autocorrelations type, timescale, and statistical properties of financial time series and benefits other researchers for more accurately modeling the financial time series.

2. Methodology

Our data is the 5 min closing price of the Shanghai Composite Index (SHCI). The sample period is from March 7, 2002 to March 20, 2012, which consists of 110,064 observations retrieved from TinySoft database. Return $G_{\Delta t}(t)$ is the percentage change of the closing price Z at time t over timescale Δt:

$$G_{\Delta t}(t) = \ln Z(t + \Delta t) - \ln Z(t). \tag{1}$$

However, all following analyses are based on the standardized return $R_{\Delta t}(t)$ at time t over Δt, which is further defined as:

$$R_{\Delta t}(t) = \frac{G_{\Delta t}(t) - \langle G_{\Delta t} \rangle}{\sigma(G_{\Delta t})}, \tag{2}$$

where $\langle \cdots \rangle$ and $\sigma(\cdots)$ represent the expectation and standard deviation.

2.1. Types of autocorrelation

To identify the influence of autocorrelation on statistical properties of financial series, we first define each type of autocorrelation in a return series. Following the previous work by Ref. [17], $R_{\Delta t}$ upon timescale Δt can further be expressed as

$$R_{\Delta t} = \mathrm{sign}(R_{\Delta t})\,|R_{\Delta t}| \tag{3}$$

where $\mathrm{sign}(\cdots)$ denotes a sign function of $R_{\Delta t}$. As shown in Eq. (3), $R_{\Delta t}$ is a product of a sign and an absolute value of itself. The potential autocorrelation underlying the return series is therefore associated with two factors: its sign and volatility. This feature creates three different types of autocorrelations: sign, volatility or return autocorrelation. To examine the impact of each autocorrelation on the financial time series, three new series are created by shuffling either one or both of the factors. Each shuffled series destroys a certain type of autocorrelation: sign, volatility or return autocorrelation. The corresponding shuffling series should be examined if one wants to analyze the influence of a certain autocorrelation [17,21,23]. Here, three types of autocorrelations and the related shuffling series are defined as follows:

(i) Sign autocorrelation (SA): The asset price presents a trend of moving up or down. This causes identical signs of returns during a period, either positive or negative. This suggests the existence of sign autocorrelation (SA). By disordering the order of $sgn(R_{\Delta t})$ and retaining the order of $|R_{\Delta t}|$ we produce a shuffling sign value series (SSVS), which destroys the order of the sign and removes most of sign autocorrelation.

(ii) Volatility autocorrelation (VA): The magnitude of asset return often exhibits a similar change during a certain period as a result of the fact that asset price rarely rises sharply (plunge) to the peak (valley). This phenomenon implies the existing volatility autocorrelation (VA). Similarly, its influence on statistical properties will be analyzed by shuffling absolute value series (SAVS). SAVS destroys the order of volatility and removes most of volatility autocorrelation. It is constructed by disordering the order of $|R_{\Delta t}|$ while keeping the order of $\mathrm{sgn}(R_{\Delta t})$.

(iii) Return autocorrelation (RA): In financial market, the asset return often remains relatively stable. Such autocorrelation related to the entire return is viewed as return autocorrelation (RA). By disordering simultaneously both orders of $sgn(R_{\Delta t})$ and $|R_{\Delta t}|$, shuffling sign absolute values series (SSAVS) is created, which destroys the order of return and removes most of return autocorrelation.